BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B71 01014

SUBJECT: A Planned Dogleg Maneuver for Apollo 14 T + 24 Launches
Case 310

DATE: January 15, 1971

FROM: T. B. Hoekstra
J. A. Sorensen

ABSTRACT

Due to the high sun elevation angle at LM landing, visibility washout is a potential problem for T + 24 hr launches on Apollo 14. The visibility conditions near touchdown can be improved by offsetting the approach trajectory plane to the north of the desired landing site. This offset increases the relative visual azimuth between the sun-site line and the LM-site line, but it requires a dogleg maneuver to land at the desired site.

The characteristics of trajectories with nominal offsets of 500 ft and 1300 ft are compared. The 500 ft offset trajectory has a relative visual azimuth of 30° at 500 ft altitude, at which time the dogleg maneuver is made. The 1300 ft offset trajectory's dogleg maneuver is made at 1400 ft altitude which also produces about 30° visual azimuth when the 500 ft altitude is crossed. The latter trajectory has the following advantages:

a) Cone Crater can be used more effectively as a landmark;

b) the ΔV cost of the redesignation is less;

c) the number of LPD inputs is less;

d) a large relative visual azimuth to the site is maintained for a longer time.

e) the bank angle of the LM at 500 ft altitude is reduced;

f) the probability of having to make redesignations to the right is significantly reduced.

(NASA-CR-116314) A PLANNED DOGLEG MANEUVER FOR APOLLO 14 T PLUS 24 LAUNCHES (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

INTRODUCTION

Mission planning for the Apollo 14 mission includes the possibility of a one-day launch delay for the second and third monthly launch opportunities. The sun elevation angle at LM landing for this so-called T + 24 launch is about 23°. Since the visibility phase elevation angle is about 16°, the crew cannot see shadows in the region of the landing site for a nominal approach. In addition, the visual contrast between adjacent features tends to be "washed out."

The visibility washout problem decreases as the relative visual azimuth between the sunline and the trajectory plane is increased. It has been suggested that the trajectory plane be offset to the north of the landing site so that the visual azimuth is about 30° at the point of crew takeover (about 500 ft altitude) for improved visibility. The crew would then make a dogleg maneuver to the desired site. An alternate method of achieving this same visual azimuth is to increase the offset distance and make the dogleg maneuver sooner. The earlier redesignation gives the crew a longer period of time with an increased relative azimuth, saves propellant, and permits the use of Cone Crater as a navigation landmark during descent. This memorandum presents a comparison between the two approaches.

TRADEOFFS FOR VARIOUS DOGLEG MANEUVERS

The visibility phase of the LM descent trajectory involves a continuous process of crew assessment of the landing site and adjustment of this site using the Landing Point Designator (LPD) and the maneuvering capability of the LM after manual takeover. Although this is a continuous process, it can be approximated by a two-step process:

a) Initial detection of navigation errors early in the visibility phase and correction of large errors with the LPD, and

b) final detection of LPD inaccuracies and selection of a touchdown spot clear of rocks and small craters by late LPD inputs plus manual maneuvering.

The trajectories considered here are designed to aid the final detection process by providing a large relative azimuth (visual azimuth) between the sun-site line and the LM-site line from an altitude of 500 ft down to touchdown. However, the initial detection problem is influenced by the strategy used to obtain the visual azimuth. To land at a preselected site by making a dogleg maneuver, it is necessary to offset the trajectory with the amount of offset increasing as the redesignation point is moved closer to high gate. For a 30° visual azimuth at an altitude of 500 ft and the dogleg maneuver made at this point, the final landing spot is offset about 500 ft from the pre-dogleg groundtrack. If the same visual azimuth at 500 ft is to be obtained by entering LPD redesignations before the 500 ft altitude, a larger offset must be used.

Several factors influence the choice of the altitude of the dogleg maneuver. To achieve the same visual azimuth at 500 ft as the altitude of the maneuver is increased, the following factors must be traded off:

a) The number of LPD pulses decreases,

b) the time during which the visual azimuth is above some minimum desired value is increased,

c) the ΔV cost of the nominal redesignation decreases (for dogleg altitudes up to 2000 ft),

d) the maximum LPD distance for the case of 3σ cross-range navigation errors increases, and

e) although the maximum bank angle at the time of the maneuver is relatively constant, the bank angle at 500 ft altitude decreases.

To simulate manual maneuvering, the dogleg at 500 ft was approximated by entering sufficient LPD pulses at the 500 ft altitude to achieve the desired azimuth at that time. Then for comparison purposes, a series of simulations with LPD redesignations above 500 ft was made in which the visual azimuth which resulted at 500 ft was approximately 30°.

After considering the various tradeoffs, a trajectory with a dogleg redesignation from an offset of 1300 ft was chosen for comparison with one having the dogleg at 500 ft. By entering 8 left crossrange LPD pulses at 1400 ft altitude from the 1300 ft offset trajectory, the visual azimuth of the LM at 500 ft increased to 27°. (The 8 pulses redesignate the site 1300 ft to the left, so if the nominal landing site is to be used, the pre-dogleg ground track must be displaced 1300 ft to the right.) The ground tracks of these two trajectories are shown in Fig. 1. Redesignations at a higher altitude which produce an equivalent relative azimuth at 500 ft would require larger offsets. The amount of offset must be limited to prevent unreasonably large redesignations for 3σ dispersions to the right.

COMPARISON OF 500 FT & 1300 FT REDESIGNATIONS

The table below gives a comparison of the two strategies:

	500 FT OFFSET	1300 FT OFFSET
ALTITUDE OF DOGLEG MANEUVER	500 FT	1400 FT
NUMBER OF LPD PULSES	14	8
RELATIVE AZIMUTH AT 500 FT ALTITUDE	28°	27°
ΔV PENALTY	60 FPS*	40 FPS*
3σ CROSSRANGE LEFT REDESIGNATION	5000 FT	5800 FT
MAXIMUM (3σ PLUS OFFSET) LPD ΔV COST	65 FPS	80 FPS

The smaller number of LPD pulses and the reduced ΔV penalty are advantages of the 1300 ft offset while the increased possibility of a large left redesignation is a disadvantage.

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*The propellant margin on Apollo 14 is currently equivalent to about 100 fps of ΔV.

Another factor which should be considered is the amount of time that the site is located far enough from the washout region to have relatively good viewing conditions. Here, it is assumed that for good visual clarity, the visual azimuth to the desired landing site must be greater than 20°. For the 500 ft offset case, the visual azimuth to the site does not reach 20° until the LM is within 5 sec of 500 ft. For the 1300 ft offset trajectory, the visual azimuth is greater than 20° for 22 sec before the 500 ft point. This gives the crew a longer period of time to assess the landing site for a more effective final detection process.

The choice of the 500 ft or 1300 ft offset also influences the initial detection process because the pre-maneuver ground track is different for the two cases. The in-the-window motions of the eventual landing site, the southern edge of Cone Crater, and the point of maximum washout (the surface location of the LM shadow) are shown in Figs. 2 and 3 for the 500 ft and 1300 ft offset cases, respectively. Clearly the 500 ft offset case has larger motion of the site in the window (about 2:1) both before and after the maneuver. In the case of the 500 ft offset, the edge of Cone Crater disappears from view 24 sec after high gate, and the redesignation is not made until 110 sec past high gate. For the 1300 ft offset case, the crater edge disappears 50 sec after high gate, and 26 sec later the redesignation is made. Thus, Cone Crater can provide a longer lasting cue of downrange and crossrange navigation performance with the 1300 ft offset distance.

The vehicle attitude motions which result from the doglegs are comparable in magnitude. The maximum bank angle (angle between LM y body axis and horizontal plane) for the 500 ft offset case is 24°. For the 1300 ft offset case, it is 26°, however, by the time the LM reaches the 500 ft altitude, the bank angle has dropped to less than 8°. The steadier, less transient conditions at this point should ease the final detection problem. In both cases there is about a 10° pitch transient.

THE EFFECT OF INITIAL CROSSRANGE NAVIGATION ERRORS

The previous discussion dealt with a nominal approach having no navigation errors. Clearly, crossrange navigation errors influence the sequence of redesignations and the probability of reaching the desired landing site in the event of washout. The 1300 ft trajectory offset decreases the probability of having to make a redesignation to the right to achieve the preselected landing site and increases the probability of having a significant visual azimuth when the LM reaches the 500 ft altitude. Redesignations to the right are undesirable because the LM Commander cannot generally see the area into which he redesignates until after the redesignation.

The following assumptions have been used to obtain the approximate probability of reaching the landing site:

a) No S-turns are used; that is, no left-right or right-left combination redesignations are used,

b) a 500 ft trajectory offset must exist when the LM reaches the 500 ft altitude point to assure good visibility during manual maneuvering.

With these assumptions it is possible to compute the probability of missing the preselected landing site. This probability has been computed assuming first that only left redesignations are permitted and second that left or right redesignations are permitted.

	PROBABILITY OF MISSING SITE	
	LEFT REDESIGNATIONS ONLY	LEFT OR RIGHT REDESIGNATIONS
500 FT OFFSET	50%	25%
1300 FT OFFSET	30%	18%

If left or right redesignations are permitted, there is a 25% chance of a right redesignation with the 500 ft offset and only a 12% chance of a right redesignation with the 1300 ft offset.

If S-turns are permitted or if a slightly off target landing is acceptable, the probability of missing the target decreases. Additional analysis and simulations are needed to establish a simple procedure giving the size and altitude of the redesignation as a function of crossrange navigation error. Such a procedure should be established whether an offset trajectory is planned or not.

SUMMARY

The acceptability of redesignations to the right, large attitude transients, and S-turns cannot be assessed without the use of ground-based simulators. However, this initial analysis indicates that there are advantages to increasing the planned trajectory offset to more than 500 ft. A 1300 ft offset distance offers the following advantages over the 500 ft offset:

a) Cone Crater is more nearly on-track and is nominally visible for 26 sec longer for better initial detection of navigation errors.

b) The ΔV cost of the nominal redesignation is less (40 fps vs. 60 fps).

c) A smaller number of LPD pulses is needed (8 vs. 14).

d) The relative visual azimuth between the sunline and the LM-landing site line is large for a longer period of time (>20° for 22 sec vs. 5 sec).

e) Although the attitude transients at the time of the dogleg redesignation are comparable (about 25°), the transient has greatly decreased (to 8°) by the time the LM reaches the 500 ft altitude point in the case of a 1300 ft offset.

f) The probability of missing the pre-selected landing site is considerably lower (30% probability vs. 50% probability if only left redesignations are permitted).

T. B. Hoekstra

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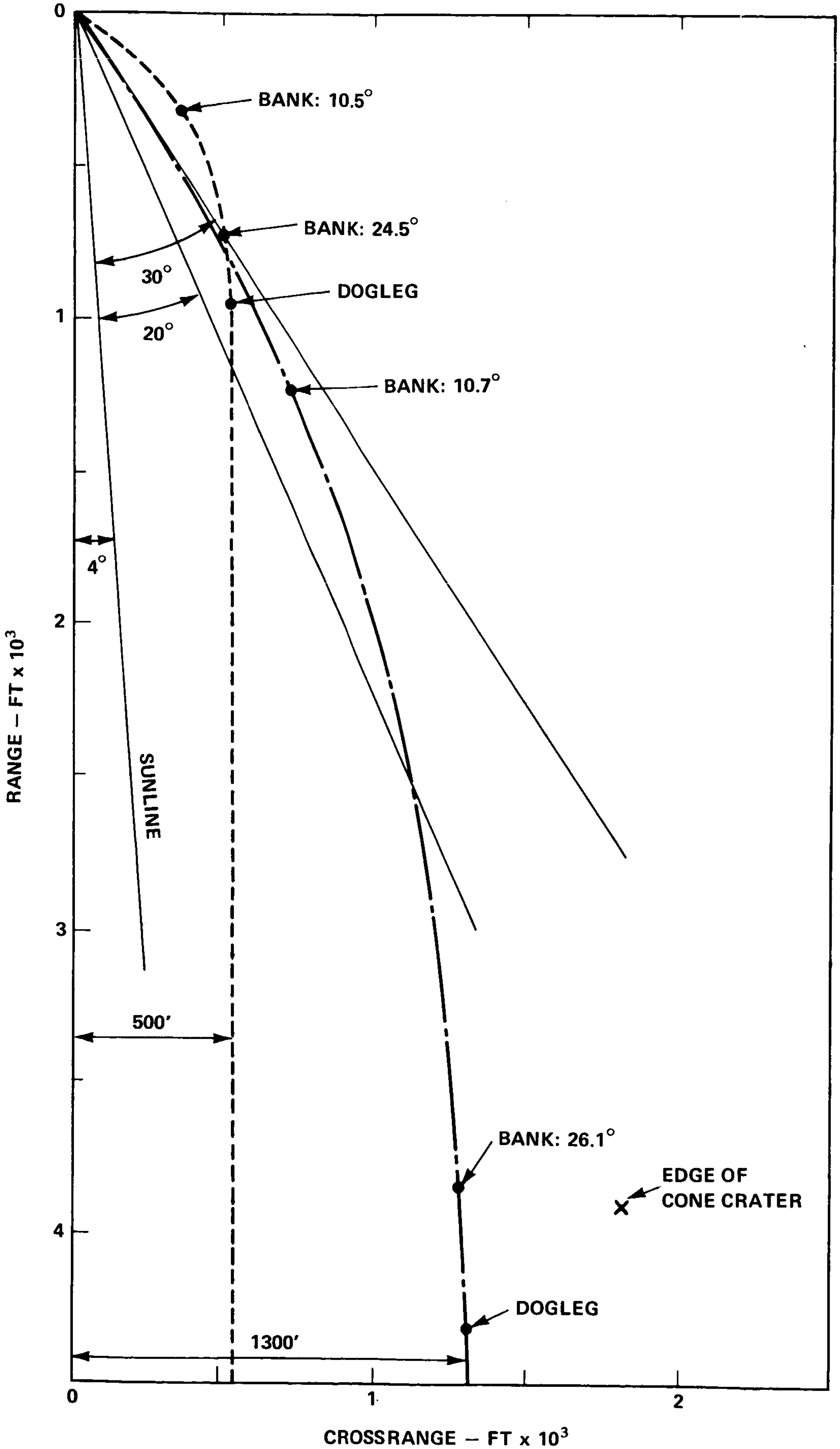

FIGURE 1 - GROUND TRACK COMPARISON OF TWO APPROACHES

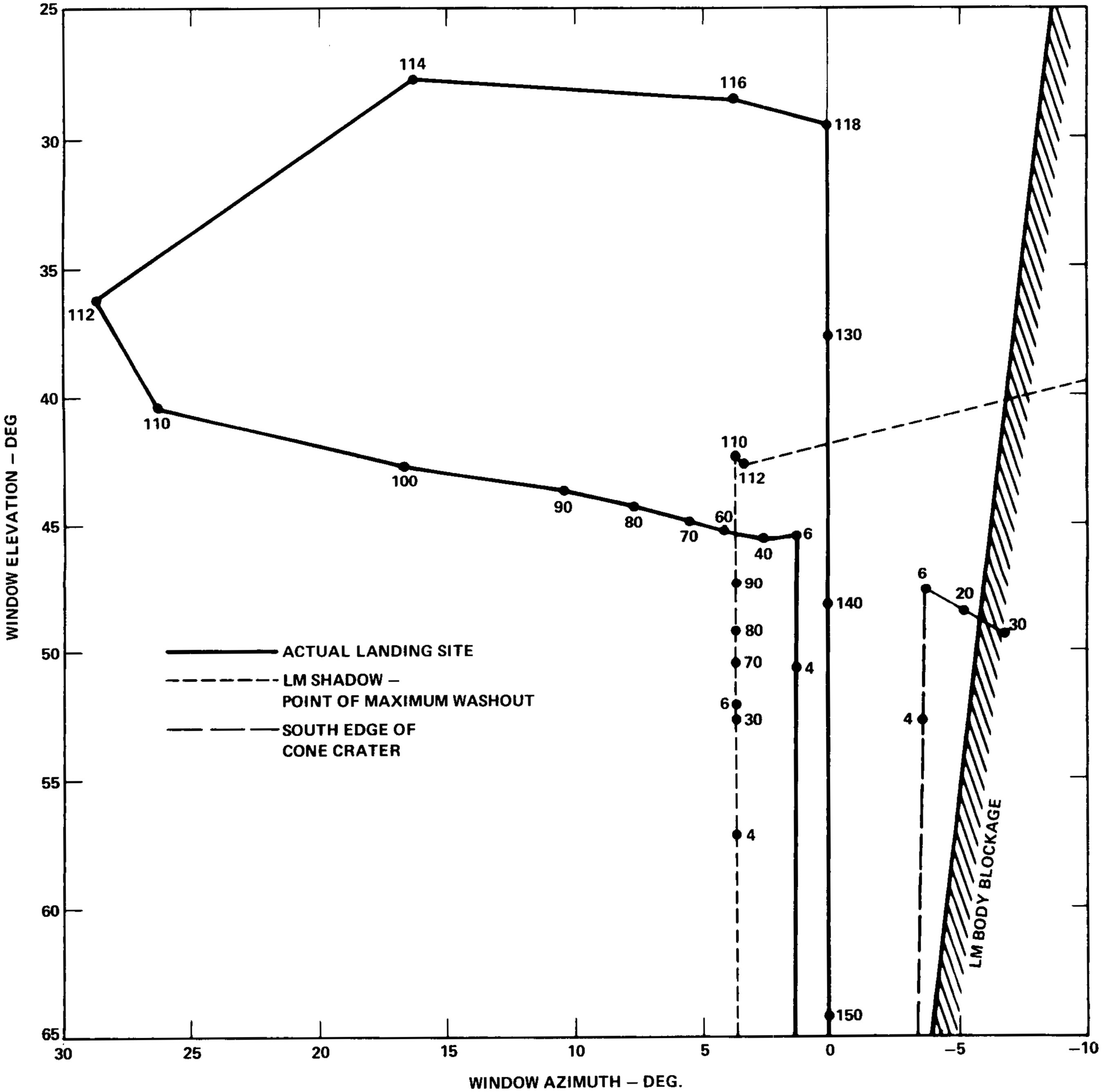

FIGURE 2 - LM WINDOW VIEW WITH GROUND TRACK INITIALLY OFFSET 500 FT. NORTH OF DESIRED SITE. REDESIGNATION TO THIS SITE IS MADE 110 SEC AFTER HIGH GATE AT 470 FT. ALTITUDE. ALSO SHOWN ARE THE SOUTHERN EDGE OF CONE CRATER AND THE POINT OF MAXIMUM VISIBILITY WASHOUT. TIME IS INDICATED IN SEC PAST HIGH GATE.

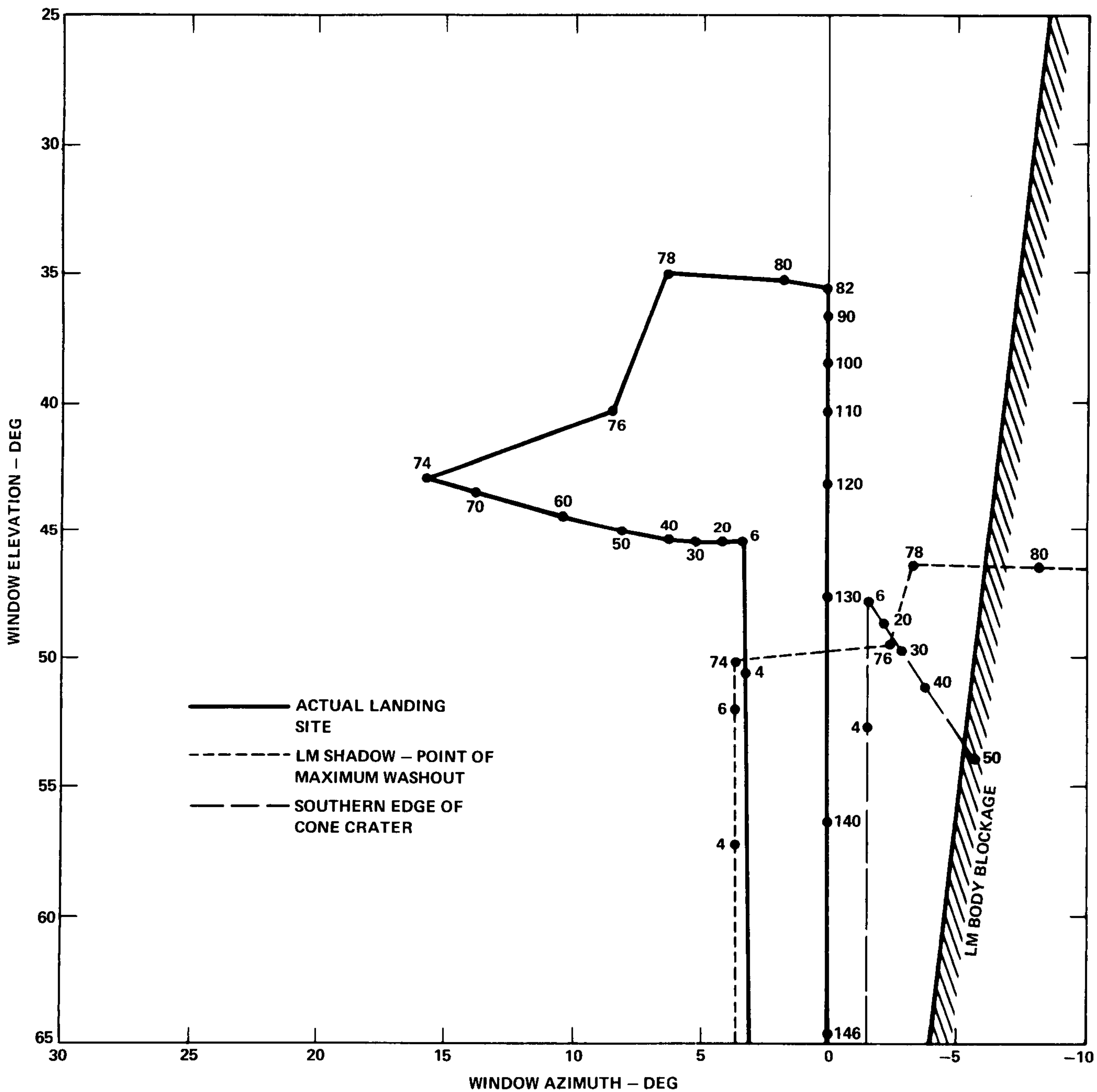

FIGURE 3 - LM WINDOW VIEW WITH GROUND TRACK INITIALLY OFFSET 1300 FT NORTH OF DESIRED SITE. REDESIGNATION TO THIS SITE IS MADE 74 SEC PAST HIGH GATE AT 1420 FT ALTITUDE. ALSO SHOWN ARE THE SOUTHERN EDGE OF CONE CRATER AND THE SURFACE POINT OF MAXIMUM VISIBILITY WASHOUT. TIME IS INDICATED IN SEC PAST HIGH GATE.